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Harnessing Technology for a Resilient Food Supply Chain in Pakistan:Tackling Inefficiencies and Food Security Risks

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The main obstacles in smooth food supply chain in Pakistan are linked with different factors like climatic changes, week infrastructures, problem related to the market orientation and lack of coordination among different stakeholders. These challenges lead to high post-harvest losses and food prices, thus threatening the national food security and stability. The review article explores how new technologies can be used to enhance the resilience of the food supply chain in Pakistan for future food security. It examines the recent academic papers from last couple of years that evaluate how digital tools such as artificial intelligence, blockchain, the Internet of Things (IoT) and data analytics can be used to improve the areas of traceability, logistics, risk management and access to the market. In addition, the review also illustrates specific challenges that were hindering the adoption of new technologies in Pakistan like lack of infrastructure, incompetent governance, and the lack of financial resources. The paper supports strategic interventions and the need to have integrated digital platforms, policy reforms and capacity-building programs to empower the smallholder farmers and the local enterprises. Finally, the article highlights that the adoption innovative technologies and policy reforms for resilient food supply chain can help Pakistani nation to cater future food security threats.

Keywords: Food security, food supply chain resilience, sustainable food system.

INTRODUCTION

The increasing concern regarding food security issues in Pakistan demanding the need of smooth supply chain that will not only affect the life of millions of people but also helpful to fulfill the huger of it increasing population. The major portion of employment of this country in directly or indirectly linked with agriculture sector where farmers produce variety of crops and livestock throughout the year. But to poor infrastructure and supply chain system a big portion of their produce loss during this chain and unable to reach their consumers as per international standards (Khan et al., 2022; Majeed, 2024). These loses only effect the economic conditions of farmers but also increasing the burden of agriculture imports and trade deficit. There are number of factors started from production, harvesting, post-harvest management, storage, transportation, processing, retail and consumers that make up whole supply chain system. The performance of the entire chain suffers from flaws create at any stage of this system e.g. poor harvesting methods, inadequate storage like lack of cold storage facilities for fruits and vegetables. The studies in past depicted that poor handling and improper storage contributing in significant of loss for field crops especially perishable goods that weaken market supply, decrease farmers earning and reducing household access to healthy food (Afshar, 2025). On the other hand, the increasing demand of fresh and perishable commodities due to urbanisation and dietary changes requires a speedy and careful delivery and storage (Dong et al., 2023). Uncertainty within the market and disruptions in global supply chains can also affect pricing and supply, so these should be resilient enough to absorb shocks, respond quickly and regain normal operations during the passage of time (Rashid et al., 2024). To improve the system of supply chain

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the use of advanced techniques, procedures are digital tools especially block chain & sensor networks and artificial intelligence are adding their positive share in forecasting, logistics and traceability of food chain worldwide (Dong et al., 2023; Ellahi et al., 2024). Different advance sensors and devices are being used to monitor and control temperature and humidity throughout the supply chain process and storage facilitates to minimise the spoilage of perishable food (Siddiqui et al., 2024). Artificial intelligence (AI) and data analytics enhance demand-forecasting and route-optimisation processes, which results in faster goods flow and less waste (Anwar et al., 2023). The use of blockchain records every stage of the product life cycle, thus boosting the consumer trust and traceability (Ellahi et al., 2024) and improves supply-chain visibility, responsiveness and minimisation of waste. An overview of blockchain uses suggests that blockchain control curbs fraud and food safety but also highlights the need to implement it in a standardised way. The implementation of AI has been linked to the enhanced supply-chain performance, and resilience is used as a mediating factor among AI implementation and performance results (Rashid et al., 2024). Additionally, research indicates that AI technologies for route optimization and demand forecasting can shorten delivery times and use less fuel in fresh food logistics and e-commerce (Anwar et al., 2023; Siddiqui, 2025). There have been empirical studies in Pakistan that have tested these theories and results of these surveys has shown positive results in traceability and record keeping (Siddiqui et al., 2024). These results also imply that technology may be beneficial just in case the local circumstances are taken into consideration along with local realities are of supreme importance. Small-scale farms are quite numerous in Pakistan, and many of them do not have sufficient access to the internet, power or funds to invest in new technologies and equipment and due to these reason the small land holders have to use intermediaries and informal market mechanisms (Firdous and Ramish, 2023). Thus, the encouragement of the use of the technology within such environments is difficult to carry out fairly and quickly. Based on these factors, the researchers reject generalisation and recommended that these technologies must be available with help of combined funding, education and supportive policy frameworks (Dong et al., 2023; Siddiqui et al., 2024).

Another fact to be mentioned is that technology may assist in minimizing some hazards, but it cannot be considered the solution to all the issues. Improved sensors and cold transport can reduce spoilage; however, it cannot correct the deep land and water inequities, lacking market principles, or flimsy quality checks (Majeed, 2024; Afshar, 2025). Examples from Pakistan and other nations demonstrate possible paths in spite of these obstacles. Low-cost sensors, mobile platforms and farmer groups have been used in pilot projects to improve cold-chain results and reduce losses (Siddiqui et al., 2024). Although scale-up requires clear governance and financial arrangements, blockchain experiments in fruit and dairy value chains to increased traceability and market access (Hakim, 2024; Ghaffar et al., 2025). The most harmful inefficiencies, such as poor post-harvest handling, weak cold chains, a lack of market knowledge, and poor traceability should be the target of technology. Smallholders and female producers are to be involved in the interventions to ensure that everyone enjoys the benefits (Firdous and Ramish, 2023).

The proposed review paper is dedicated to the application of technology to make the food supply chain in Pakistan more resilient. This is going to reveal the spheres of inefficiency, outline the key threats to food security, test particular technologies and pilot projects in Pakistan, and subsequently provide strategic recommendations that will tie up technology with inclusion, policy, and financing. Pakistanis needs more food as well as efficient and equitable methods of getting food from farmers to plates that can be only possible by creating local solutions, capacity building, and supportive policies linked with new technologies.

***Overview of Food Supply Chain*:** The food supply chain is a complex network, including numerous companies collaborating with more than one sectors while maintaining their own autonomy and identity in which agriculture sector is seen to be significant in terms of monetary worth and consumption. Any interruptions at national, regional and international level in food supply chain network disturbed the food accessibility networks. The major purpose of food supply chain network is to provide uninterrupted supplies throughout the year with the assurance the safe and healthy products. Quality assurance and safety in food supply chain of Pakistan have become critical areas for researchers and investigators in the most recent time due to different reasons. Scholars and professionals are being carried out their research work along with exploring the areas for developing strategies to uphold the safety of food products across all stages of the supply chain. Like other sectors in Pakistan, the food supply chain sector is behind the rest of world especially in perishable products like meat, milk and fruits & vegetables that leads to major post-harvest loss of these fresh products (Hassan et al., 2023).

***Key Players in Supply Chain*:** Food supply chain in Pakistan is a complicated network involving numbers of stakeholders at numerous stages from production to consumption in food supply chain. The supply chain starts with farmers (producer), who are significantly smallholders or producers operating on the land of less than five hectares who hold about 90% of the farming community, are engaged in supporting agriculture and contribute primarily to national food supplies. But these farmers have lack of resources to boost up their economic health but on the other hand big farmers and producers have significant access to the market and resources, enabling higher production efficiencies. The other part is commission agents, also play a crucial role in traditional agricultural markets. They facilitate supply input, salesand provide credit.

Due to limited credit access, farmers usually rely heavily on intermediaries, which affects their bargaining power to reduce price and also influences over pricing. In the next step wholesaler buy produce from intermediaries to supply retailers, processors, or exporters, influencing distribution efficiency and price formation. The food processing industry is a main part of the food supply chain, involving flour mills, rice mills, edible oil refineries, dairy processing plants and sugar mills. Major companies in this sector include Engro Foods, National Foods and Nestle Pakistan which hold significant market shares and also influence supply chain dynamics. Distributors handle moving processed foods and logistics from manufacturers to retailers. Traditional retail dominates in Pakistan, with street vendors, open markets and small shops accounting for about 95% of food retail sales (Abedullah and Naurin, 2022). The figure 1 illustrated the complete structure of supply chain cycle of mango fruit that is major agriculture export commodity in Pakistan.

***Purchasing Food from Farmers*:** Purchase of food produce from farmers depends on the middleman who affect the farmer's negotiating power and the farmers only get 20-30 % of the price while 70-80% price id received by middleman or intermediaries. Farmers are unable the access the direct customers or digital platform for the sale of their produce that affect the farmers ability to estimate the price and affect their bargaining power. Moreover, bad road structure and poor transport facility also affect the price of food produce (Ahmed et al, 2017). Along with other issues storage facilities in Pakistan are also inadequate which leads to post-harvest losses of about 15-40% after harvesting (Ahmad et al, 2021).

***Regulatory Bodies*:** The food supply chain in Pakistan is regulated or monitored by the federal as well as provincial bodies, each of which is responsible for different aspects of food trade, production and safety.

***Ministry of National Food Security & Research (MNFSR)*:** The ministry of national food security and research is the main federal agency responsible for economic coordination, policy formulation and planning in respect of food agriculture and food grains. Its main functions include agricultural development & research, quarantine service and plant protection, regulation of agricultural import/exports and coordination with the international organizations.

***Provincial Food Authorities*:** Provincial Food Authorities which include the Sindh Food Authority (SFA), Punjab Food Authority (PFA), Balochistan Food Authority and Khyber Pakhtunkhwa Food Safety are responsible for food safety and quality control within their provinces. The main responsibilities of these authorities include implementing food safety regulations and food safety standards, conducting inspections and enforcing compliance among food businesses, issuing licenses and certifications, and raising public awareness about food safety.

***Competition Commission of Pakistan (CCP)*:** This commission includes quasi-judicial and independent quasi regulatory body responsible for enforcing the Competition Act, 2010. Its mandate includes preventing anti-competitive agreements and prohibiting abuse of dominant positions including promoting competition and controlling deceptive marketing practices to protect consumer welfare and economic efficiency. To meet its objectives, the Commission is empowered to conduct investigations, enquiries, research studies, issue policy notes & inspections, issue orders and opinions after following the procedure under the rules and regulations.

***Pakistan Standards and Quality Control Authority (PSQCA)*:** This ministry is under the Ministry of Science and Technology develops and enforces standards for food products and services including food items. Its functions include certifying products for compliance, establishing national standards, preventing the sale of sub-standard products, import, manufacture and coordinating with international standardization bodies.

***Federal Seed Certification and Registration Department*:** These both departments regulate product seed quality to make sure the availability of high-quality seeds to farmers and impacting agricultural productivity. Its functions include seed certification, testing and enforcement of the Seed Act, 1976 (amended in 2015) and registration of new seed varieties.

***National Animal and Plant Health Inspection Service (NAPHIS)*:** The main purpose of this authority to oversees sanitary and phytosanitary measures to protect animal and plant health. Its functions include preventing the introduction of pests and diseases, facilitating compliance with international trade standards and implementing quarantine regulations.

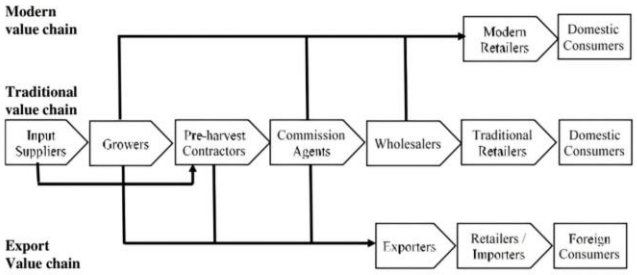

Figure 1. Structure of supply chain in Pakistan's mango industry (Badar et al., 2019).

***Modern Supply Chain*:** The increased in per capita incomes and rapid urbanization have substantially transformed the food supply chains and agriculture sector. This is mainly due to changes and disruption in patterns of food consumption which have primarily changed the consumption of simple food products such as grains to highly processed food products, processed fruits & vegetables and milk & milk products. These disruptions have also forced the under develop countries to rearranged or re-organize their availability, production, processing, marketing and

advertising arrangements. It also includes the linking of smallholder growers or producers with the Modern Food Supply Chains that have the ability to interlink growers or producers with manufacturers for more values addition. These chains have also been gestating under the networks of agriculture production of food such as global food value chain i.e. related to successfully utilizing the available resources such as physical, human and financial to minimize the overall costs associated with the food supply chain (Mazhar et al., 2022).

***Food Supply Chains issues in Pakistan*:** There a lot of issues that effecting the food supply chain sector in Pakistan like uneven growth in the agricultural sector harming the resiliency of farmers and the productivity of farms. The detail of some of the key issues as given below.

***Declining Productivity and Output*:** Pakistan's agriculture sector is going downslope and this challenge that stretched over years has now gotten serious. The main crops are projected to decline by 13.5% for the 2024-25 cropping year and during the crop year 2023 faced the challenges of declining cotton, wheat, and maize production by 30.7%, 8.9%, and 14.7%, respectively (Hussain, 2024). The crisis is due to lack or refusal to integrate mechanized farming, multiplication of stagnant farming and post-harvest practices. The inefficiencies within the Pak industry are deep whereby inefficient resource inputs are having a detrimental effect on production. Numerous studies capture these inefficiencies - the misuse of water and the evaporation and seepage losses are the most critical. Small farmers, those with around 5 acres to cultivate, are severely constrained with inputs, as quality seeds and balanced fertilizers become scarce. Land fragmentation and limited technological investment can cause additional inefficiency challenges, especially with unreliable climate conditions, unstable policies, and climate variability (Abid et al., 2011).

***Post-Harvest and Processing Issues*:** Pakistan has high post-harvest agricultural losses of 20-40% for different crops and its greatly harms the economy and food security. More recent works show there are indeed post-harvest challenges like Ahmad et al. (2021) reports 35-40% of fruits and vegetables are wasted after harvest and this happens during postharvest as a result of mechanical damage, mishandling and the absence of modern techniques. Firdous (2021) also supports this by stating that postharvest losses in developing countries are 30-50% as opposed to less than 15% in developed countries. The reasons for losses include poor infrastructure, minimal cold storage, inefficient distribution, and low technical know-how. These losses can be alleviated through partnerships between the government and the private sector aimed at market accessibility. This includes the construction and modern farmland development that improve value chain bus infrastructure.

***Inefficient Distribution and Logistics Systems*:** Significant structural dysfunctions within the logistics sector in Pakistan weaken the supply chain in the agriculture sector. Studies conducted over the past few years can show how poorly Pakistan has performed within this sector and data depicted that from 2016 to 2023, the country dropped in the Logistics Performance Index from 68 to 122 out of 160 in the world. The country faces issues within its transportation infrastructure and most of the freight in the country (over 96%) is transported through low quality unrefrigerated trucks. These issues within the sector have resulted in significant economic loses, particularly in the agriculture sector e.g. fruits and vegetables loss is estimated between 25 to 30% after harvesting (Ayyaz et al., 2024). This gap in refrigerated transport disrupts rural-urban production linkages, causing a loss in the economic value and perishable quality of produce degrading. The pathway to achieving these objectives is investments in cold storage, more specifically modular cold storage, and farm-gate to reduce agricultural losses. Therefore, full economic losses within the cold chain sector, will diminish and losses from inefficiencies will remain in the agricultural sector in Pakistan. The issues can be solved by the new smart logistics platforms using ICT and other technologies that has the potential to revolutionize the distribution of agriculture (Majeed, 2024).

***Food Security Risks in Pakistan*:** Food security is a multifaceted issue that can be understood through the integration of three fundamental aspects: food availability, accessibility, and utilization. The challenge of food insecurity arises not only from insufficient food supply but also due to lack of purchasing power and access at both community and household levels. Like many other developing countries, Pakistan is recognized as one of the countries which is most impacted by food insecurity, poverty, and environmental challenges. About two-thirds of the population in Pakistan lives in rural areas and depends directly or indirectly on the agricultural sector for their food and lifestyle from which their lives impacted greatly (Ahmed et al., 2017). Pakistan is self reliant for food because of its agriculture sector but it has only achieved 30 percent of its potential. Studies shows that, the average food intake of its population is still below then established standards for public food security. The research also indicates that the country has an available food supply approximately 30 percent. Furthermore, 35 percent of the food that is available goes unutilized due to various factors, such as physical, economic, and sometimes environmental factors. Among the seven administrative regions of Pakistan, Punjab and Sindh are the primary areas for food production. In contrast, the Federally Administered Tribal Areas (FATA) experience the most severe food shortages due to less utilization and availability of resources. Despite of local food generation, a food gap persists in all administrative regions due to challenges with food availability and distribution, the availability of food products, inadequate monitoring of marketing systems, limited purchasing power, and natural damage (Hussain and Routray, 2012).

***Climatic and Environmental Risks*:** The most serious and complicated issue we face today is climate change. It is a global challenge that affects every part of life: society, politics, the economy, and science. The impact of climate change varies greatly from one region to another. In Pakistan, the effects are especially severe due to rapid melting of the Himalayan glaciers, irregular rainfall patterns, flooding, droughts, water shortages, temperature fluctuations, storms, landslides, pest invasions, shifts in seasonal timing issues contribute to this problem. Climate change has hurt the overall economy, but small farmers have been hit the hardest and flooding has greatly reduced their overall yield and disrupted their lives style (Tabasam et al., 2022). Studies shows that climate change has already impacted the productivity of major food crops like wheat, corn, and rice, which are staple foods in many countries. The effects of climate change on these important crops are well-documented. Increasing salinity and changing ocean conditions are expected to negatively affect crop yields in the coming decades. However, the impacts on livestock and fisheries, which are also vital for food security, have largely been ignored which us very critical situation. Climate changes such as extreme temperature stresses, changes in rainfall patterns and intensity, and other climate-related disasters will make farming more difficult in coming years (Farooq et al., 2022).

***Social economic risks*:** The Chine-Pak Economic Corridor (CPEC) initiatives in Pakistan meets serious environmental issues that adversely affect the nation's development and economy. To tackle these conditions immediate attention is needed for these major issues like deforestation, loss of biodiversity, and pollution from large-scale projects. To deal with these challenges, we must apply effective environmental management and sustainable practices in CPEC projects. This strategy will help reduce harmful impacts and promote long-term sustainability. Given the climate change events impacting Pakistan, it is particularly crucial to consider these factors. Due to recent environmental, ecological and economic issues there is need of proper economical balance and environmental sustainability. This highlights the need for a clear plan to promote environmental sustainability in development projects. Despite these challenges, the CPEC systems aim to support sustainable development by using renewable energy sources. The long-term health of the environment depends on producing energy from these renewable options. Reviews and researches showed that Pakistan's economy mainly depends on agriculture, which has a growth rate of 2.77 % and its accounts for 19% of the Gross Domestic Product (GDP). In 1960, agriculture contributed 29% to GDP, but this figure decreased to 18.9% by 2020. About 26% of global greenhouse gas (GHG) emissions are linked to food production. Pakistan's agriculture industry faces issues such as carbon emissions from burning fossil fuels, which affect food production and contribute to climate change. To deal with these problems, it is important to utilize modern and sustainable farming practices. This includes using renewable energy technologies and efficient farming methods and awareness among farmers. Improving agricultural productivity and sustainability is very important for Pakistan's economic growth and environmental health (Adnan et al., 2024).

***Risk management*:** Most of the farmers in Pakistan depends upon agriculture sector for their income and surveillance. The dependence of farmers on agriculture sector along with limited access to financial resources and support services, makes them susceptible to poverty. They need to feed their families while paying back loans at harvest time, which harms their cash income and ability to invest ultimately leads to poverty. Smallholders see price and yield changes as major factors affecting their earnings. Meanwhile, other risk factors such as shifts in input costs, agricultural programs, government policies, and land rental rates are viewed as less serious threats to their income. Rather than using forward pricing and crop insurance, small farmers usually keep financial reserves and diversify their activities to manage risks. However, most do not understand the risk/price trade-off that comes with different risk management strategies. The various risks faced by smallholders in the country and their effects on farmers' livelihoods so to tackle these situations and risks there is need of proper management and sustainable practices (Hussain, 2024).

***Role of Technology in Food Supply Chain*:** Digital technologies are defining the resiliency of the food supply chain in five important technological domains such as precision agriculture, cold-chain logistics, block chain traceability, AI analytics and digital marketplaces (Sutar et al., 2025). These systems have the opportunities to bring systematic improvements in supply chain delivery in four key dimensions and these are visibility, predictability, responsiveness and adaptability. In particular, block chain, IoT and AI are also useful in making food system accessible, stable, and available. The precision agriculture, artificial intelligence, block chain and the Internet of Things applications (IoT) have already become the main list of key technologies that could be utilized because of the current crises (Konfo et al., 2024). And they will be able to make the supply chains more resilient; giving them enhanced visibility and traceability and enhanced adaptability. In fact, the downstream companies are adopting digital platforms in order to create proactive mitigating action plans with the less upstream partners and a number of recent studies consistently demonstrate how digital innovations can remove disruptions and improve the performance of operations and create more resilient food supply ecosystems (Su et al., 2023). Precision agriculture technologies are innovative digital instruments, which provide the possibility of the effective utilization of resources and farm yield growth with the help of data-driven observation and control. Such technologies as remote-

sensing, GPS-enabled devices, variable rate technology (VRT) and IoT devices are important in smart farming (Getahun et al., 2024). They are those technologies with which farmers can track the state of crops, soil and environmental parameters in a real-time, which makes them resource efficient. The evidence is good (Harsanto et al., 2025) they systematically analysed sixty-five publications on disruptive agricultural technologies and emphasized the fact that they had the potential to enhance food security, climate change and resilience. The methods can be employed to conserve water and fertilizer, reduce pollution and help the farmers to make improved choices. Adoptions are however challenging due to the high cost involved as well as technical complexities.

The use of Intelligent Logistics technologies is transforming the post-harvest management by helping to reduce food losses and supply chain resiliency in low income countries by a large margin. Research has indicated that the rate of perishable food waste can be reduced by 1525 percent in pilot chains with the application of digital monitoring. Some of these technologies in this world include IoT sensors, AI driven predictive maintenance, GPS route optimization, etc. (Firdous, 2023). These technological inventions address some of the most urgent issues in the food system in a world where 40 percent of all perishable food is wasted after harvest due to poor storage and transportation. Sensor technologies will be able to offer a real-time monitoring of temperature and humidity, forecast the equipment servicing or substitution of routing. Nevertheless, successful implementation of the programs in field, particularly in LMIC is not easy to achieve, particularly they have limited hardware and capital resources. The traceability requirements of the food supply chain can offer unmatched transparency and protection in the chain of origin due to the decentralized, seamless nature of block chain technology. According to various studies, block chain might uproot the food tracing system. The primary benefits are the quick response to an emergency due to the immediate detection of contaminated batches forms of contamination (Ahmad, 2021) and avoidance of fraud (the ability to have unchangeable records of transactions).

***Implication to Policy and Research*:** To address the technological, infrastructural, and capabilities issues, the digital transformation of food supply chains needs a multi-faceted policy response to ensure the success of the implementation of the process. Another aspect of technology adoption is human capital: farmers, logistics operators and regulators must be trained to effectively use digital tools. Demanding reliable internet connectivity, affordable devices and access to electricity must be the priority to the development of digital infrastructure. Some key policy recommendations include open data standards to prevent information siloes, cross-sectoral government-led collaborations with academia and private sectors, and designs for digital ecosystems that integrate sustainability concerns. Future research needs to be centred on developing a unified platform linking farm data, logistics data, and market indices enhance the resilience of supply chains (Sutar et al., 2025).

***Technological Innovations for Supply Chain in Pakistan*:** Innovations are one of the most promising techniques which persuades a resilient and sustainable food supplied throughout. The basic perspective is to fill the gap between the technological innovation and supply chain performance in SMEs (Ahmed et al., 2021). Digital technologies after industrial revolutions have been reframing. Technologies like blockchain, artificial intelligence and internet of things (IOT) enhance organisational activities to become more flexible and efficient. Pakistani is an agricultural country so digitalization in this sector proves to be more tremendous and efficient for supply chain. Automatic and robotic indicates contrasting approaches from each nation's having a unique economic landscape, agricultural background, industrial structure, market dynamics and labour. Larger factories like textile, food processing and pharmaceuticals use this technique for packaging, sorting, moving materials and repetitive tasks to improve efficiency and consistency having competitive advantage through design and precision in innovation. Increased productivity, greater efficiency, reduced production cost, minimised manufacturing errors, optimised inventory level, increased contribution to global GDP and enhanced production flexibility are the key factors for having a better relationship with sustainable supply chain for entrepreneurship. A recent report published by Mckinsey Global Publishing (2023) indicates that effect of automation on global economy projecting about 5 trillion dollars to global GDP by 2030 (Bala et al., 2024).

In the era of blockchain technology a technological advancement which are quite important for economy's growth. Blockchain gives transparency in all the SC activities either from raw materials to product delivery at the end of consumers. So, with technological development, different hesitations surround its implementation which aims to investigate the factors affecting blockchain adoption and implementation. Therefore, by evaluating its impact on supply chain performance a persuasive model has been used in a lot of studies on the acceptance of information technology systems to level up professional supply chain in highly diversified manufacturing sectors. It gives transparency, traceability, security and efficiency toward products e.g. mangoes and meat are used in supply chain (Ahmad et al., 2021).

***Eco-friendly supply chain management practices*:** In eco-friendly supply chain management practices partial least square-structural modelling (PLS-SEM) has been implemented. GSCMP practices has shown a positive and direct impact on technological innovation and with operational performances. This method limits an extreme ramification on human welfare, effective activities and the surroundings which in term gives a better, reliable and

sustainable atmosphere globally by avoiding environmentally damaging operations. It's a feasible solution and its prevalence spikes around 2000 through investigative or scientific publications. Firms, irrespective of size, it's constantly competing in order to manufacture innovations in different items at a cheaper cost with less damage to environment to improve quality, design and other services. Innovations in different technologies promote the mutualism in between the GSCM techniques and operational performance. Due to lack of research only a few industries are using green technology in Pakistan (Khan et al., 2022).

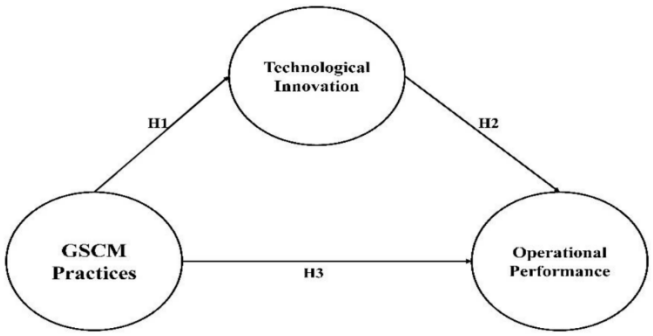

Figure 2. Theoretical framework.

***Challenges in Technology Relinquishment*:** There are certain challenges that beget issues in enforcing ultramodern technologies in Pakistan's food force chain. There's no mistrustfulness that ultramodern technologies promise translucency and effectiveness but certain hurdles like structural, fiscal and artistic or social cause problems in its perpetration. Presently, relinquishment remains limited and only twelve of Pakistani growers use digital husbandry tools similar as satellite imagery, soil detectors, and ranch operation software. Some other technologies like remote detectors, drip irrigation, drones and climate smart practices allow growers to make informed opinions and smart soil health monitoring helps growers apply diseases more efficiently, reducing input costs by 25% but long- term changes and relinquishment of these and others technologies show both positive goods and certain problems. The perpetration of these technologies in long term especially by pastoral areas of Pakistan is delicate because of its high perpetration cost and the growers in pastoral areas have no fresh knowledge of these technologies (Akram et al., 2024).

Advanced technologies like Blockchain, IOT and big data have shown significant benefits. Blockchain is transformative because it can keep record of food from ranch to chopstick and help food fraud. Despite its implicit benefits, the relinquishment of blockchain technology in Punjab's food force chain remains limited due to colorful challenges, including high perpetration costs, lack of specialized moxie, and nonsupervisory enterprises (Akram et al., 2024). Although this technology is wide in US and China but its relinquishment in developing country like Pakistan remains a challenge because of its high cost, no specialized moxie and poor structure. Complex blockchain will inescapably affect in advanced expenditures to support more calculating power by the platform. Advanced costs are anticipated to be incurred by colorful actors in the process of transitioning from traditional SC practices to blockchain- powered Agri- food SCs (Menon et al., 2021). Around seventy percent of small growers cannot go ultramodern technologies without fiscal support or subventions. The other issue is that the smallholder growers in Pakistan have low access to bank loans that have no interest cost with it. The growers in Pakistan are not familiar with husbandry related loans and because of that they take loans from the unofficial peoples with sky high interest rates. Lower small holders who in principle are supposed to have the loftiest access to formal credit have negligible access to similar credit (Batool et al., 2021) and because of that the growers with income enough to just support their families have no redundant means to invest in the ultramodern and advance technologies like IOT, Block chain, big data and cold force chain. So, indeed though advancement in respects to technology in Pakistan food force chain is possible and is enforced in large scale land possessors it is not commercially doable for small scale land possessors and that's why they're bound to use the traditional husbandry styles due to which the product rate is dwindling and they're unfit to make further income.

***Structure Limitation*:** The other limitation that occurs in the way of enforcing these ultramodern technologies is the pastoral weak structure in order to transfigure the Pakistan's food force chain to make it digital and dependable. There are certain effects that we need like electricity, internet and well-equipped transportation medium and unfortunately, in some of the pastoral areas of Pakistan it is not present. it presently seems impracticable to propose perpetration of blockchains with limited relinquishment and dispersion of complex digital structure and enabling technologies similar as RFID, IoT, NFC, pall computing, and big data (Menon et al., 2021). There are numerous Agri affiliated launch- ups in Pakistan that's gaining instigation and helping planter achieve the asked results. Digital knowledge is a major constraint, with only 26 of pastoral Pakistanis having access to or using the internet the growers with small effects are generally not well educated and they do not know how to operate the digital tools and indeed smart phones. They are not familiar with digital tools and do not have request access. Other limitation is the weak structure and the growers are not familiar with cold force chain due to which utmost of their perishable goods get destroyed on their way to the request. There are limited public and private sector collaboration and between stakeholders. The structure issue and the unstable power force not only beget issues in the way of enforcing these digital tools also due to this reason numerous stakeholders do not want to invest

in these types of technology that need constant monitoring and electrical force.

***Lack of specialized shops*:** Likewise, Education position of growers in Pakistan is 56.3 and 43.8 for 10 or lower training times and above 10 times of training independently and in China 9.84 and growers have lower or 10 and over 10 training times of education. Because of it they warrant necessary specialized shops, not only grower lot of distributor and processors also do not have the necessary specialized shops to operate the advance technology. Low digital knowledge is another hedge, over 60 of grower's warrant smartphone access, limiting the reach of mobile- grounded results, AI tools, and digital commerce. Because of this limitation it's substantially delicate that the growers will know about the digital changes that's happing in the world of husbandry that further limit the digital agrarian advancement in Pakistan. Only 15 of growers presently use digital platforms for dealing their yield. The ignorance of growers with the online selling word made them unfit to vend them produce directly to the request and with its addition with unstable cold chain force structure cause at least 40 losses of perishable husbandry yield. Digital metamorphosis presents significant openings for businesses in Pakistan's agrarian assiduity to enhance their performance and competitiveness. Still, to completely realize these benefits, businesses must address the challenges posed by digital metamorphosis, including the need to acquire digital chops and ameliorate digital structure (Batool et al., 2021) and with that the perfection husbandry and the digital reforms in Pakistan are underdeveloped. Without the collaboration of educational and other private sector and the targeted training institutes these reforms are delicate to achieve in the pastoral areas of Pakistan.

***Policy Gaps*:** Regulatory query around blockchain systems and digital deals. Pakistan presently lacks clear guidelines and regulations for the use of blockchain in business operations. The lack of norms and laws related to blockchain can produce misgivings for manufacturers, service providers, and consumers likewise (Menon et al., 2021). This query deters stakeholders from investing in and enforcing the technology. This also beget other private sectors to invest in this kind of uncertain system and make it delicate to apply blockchain technology in the force chain of Pakistan. The blockchain technological system is composed of a series of data blocks, which are defended by a public key and a private crucial and bear a timestamp. Blockchain technology is not governed by formal nonsupervisory fabrics, creating valid enterprises regarding sequestration, confidentiality, data security and governance (Menon et al., 2021) these kinds of data sequestration issues farther delay the relinquishment of Blockchain relinquishment. The government of the developed countries like the China and EU have developed the standardized frame of blockchain technology and it's working well but, in Pakistan this is not passing at the position it has to be because ever sector then work in insulation and they are not linked. The policy maker should have to work on this and made inventions that give the asked sequestration factors so that both the investor and the planter feel safe.

***Cultural, Organizational and Behavioral Hedge*:** In developing countries, there is not only fiscal, specialized and educational issue in the way of espousing the advance technologies but also the gender peak is stark, only of womanish growers have access to Agri Tech tools, leaving a large member of the agrarian pool barred from the benefits of big data (Agri economist). also, there comes the Organizational resistance, it's a common coexisting factor with change that can be viewed as a dominant hedge to the relinquishment of new technologies (Imran et al., 2025). The growers in the pastoral areas of Pakistan are not familiar with advance technologies due to which they prefer traditional ways over the ultramodern bone.

***Strategic Recommendations*:** Of studies that planned results to drop food leftover and attractive flexibility in the Food supply chain, developing technologies shown usefulness in the emergent adaptive organizations in the Food supply chain. Artificial intelligence, machine learning, blockchain, Internet-of-Things, digital twin, and data analytics are some emergent technologies that play important parts in speaking to the several trials faced by changed supply chain organizations (Sutar et al; 2025).

Internet of things connects physical things to form a network of 'things', like buildings, vehicles, machineries, products food, wearing accessories and appliances home. These physical items are installed with electronic, software, radars, and network connectivity, which enable them to collect data, intelligence their surroundings, detect limitations like temperature and moistness, and transmit the collective data through internet for further analysis and real time, deciding (Sutar et al., 2025). Internet of things is considered as a promising technology that enhances the value of life and reduces human labors. It has been widely used in various fields like smart city, industrial, health care, and supply chain. In SCM, Internet of things has gained additional attention than other technologies as it enables the integration of devices, data collection devices and communication schemes to collect real time data on various limitations of perishable products like temperature, moistness, and gas concentrations. Utilizing internet of things devices would enable sponsors to consistently track the quality progress of fresh products across all supply chain stages and take prompt action in case of any possibility problems (Seyam et al., 2024).

Integrating blockchain into supply chain companies allows for the holding of all information, notifications, standing, and messages in a mutual unopposed record accessible to all sponsors, thus achieving data slide (McClements et al., 2021). Machine learning can play a vital role in decorating different aspects of the supply chain organizations, resulting in further improved efficiency, less waste, and better decision-making. Numerous literatures highlighted the role of using Machine

learning algorithms to report various supply chain activities such as food product preparation, information processing, prediction, and automated decision-making (Seyam et al., 2024). Within SCM, it refers to the process of creating a virtual representation or twin of a product across the supply chain. Its facilities the ability to observe, simulate and predict the physical product's behavior, therefore allowing stakeholders to take proactive measures to enhance efficiency and enhance decision-making within a supply chain (Zia et al., 2024).

Information Technology play a critical part in allowing flexibility in Food supply chain systems like Siddiqui et al. *(*2025) argued that technical apparatuses meaningfully donate to speaking hesitation through simplifying real time data sharing amongst investors. Also, highlighted that skill replaced as a substance to improve flexibility in the supply chain over supportive teamwork, perceptibility, and info distribution. In addition, Artificial intelligence and Machine learning processes have huge possible to progress source chain flexibility by nursing and forecasting information tendencies, attractive data dispensation abilities, and enlightening making result policies (Iqbal et al., 2025). Lately, there has been an increasing interest in adopting Artificial intelligence and Machine learning representations to protection source chain systems from disturbances, important to enhanced flexibility. Internet of things strategies, such as Radio Frequency Identification (RFID) and devices, can be used to pathway goods, gather real time information, progression data, and offer directors with the essential info for effective and active policymaking.

While many studies have encouraged for using developing technologies to development resilient and healthy systems that talk the exclusive features of food supply chain systems maximum of these trainings are also appraisal and argument documents or still in the initial phases of theoretic conceptualization and demonstrating, missing operation or trying based on real life case studies. Additional detailed study is desired to tie this hole and progress applied and know-how-based answers to improve flexibility in the food supply chain. Additionally, contempt the growing curiosity in accepting Internet of things, few research answers have authenticated its efficiency in enlightening supply chain flexibility distinguished that individual 11% of supply chain related articles absorbed on Internet of things. Additional study is desired to discover and test the abilities of Internet of things knowledge in attractive supply chain elasticity (McClements et al., 2021).

Technology implementation could successfully address issues like food perishableness, freshness level, and correct prediction so as to reduce food waste. For instance, Artificial intelligence and Machine learning processes allowed the development of estimate models for fresh products' shelf life. Internet of things could play a critical part in monitoring and following product value and infection sideways supply chains, thereby reducing leftover (Rasul et al., 2021). Notwithstanding the rank of the implementation of blockchain with the aim of reducing food leftover, the integration of blockchain skill into the Food supply chain was primarily associated with appealing slide and traceability to confirm food safety (Siddiqui et al., 2025). It was also revealed that integration of blockchain with Internet of things raised as the key technology in achieving the objective of traceability along the food supply chain. Further exploration of the role of emergent technologies in changing food waste could affect critical enhancements in sustainability and efficiency within the food supply chain. This research has investigated, in light of the Covid-19 disaster, the causes and impression of food insecurity on public well-being. In attracting flexibility and sustainability into food safety, the study focused on the similarities, differences, and interrelations among these two concepts of sustainability and flexibility within Food supply chain systems. To that effect, there were outlined sustainable policies and activities for making strong food supply chain. Mixing in sustainability and flexibility is and plays an essential role, cautiously entwining them with healthy business performances and financial growth, thus attaining resilience and sustainability. Engaging sustainability and flexibility in the proposals of the food sector proposes a gathering of benefits, mainly in ensuring food safety and meaningfully influencing public health. One of the leading benefits is found in the dependable access to nourishing food by inhabitants. The performances done for the role of sustainability in agriculture and food manufacture ensure the durable usability of the food sources, protecting their variety and abundance. This flexibility of the food organization plays the role of a safety net in cases of disasters or disturbances, ensuring the risk of food lack and speaking to an essential characteristic of community health-access to adequate nutrition. Moreover, engaging flexibility approaches provides support for the skills of the food subdivision to outlive shocks and disturbances. Whether opposite to climate-related gestures, supply chain conflicts, or worldwide epidemics such as COVID-19, a resilient food system adjusts and roles professionally. This flexibility ensures firm food provision, efficiently limiting food uncertainties that can essentially affect community outcomes (Akram et al., 2024).

Additional serious advantage is the improvement of food security and value. Sustainable practices fundamentally order food security and quality standards. When combined with flexibility policies, these performs strengthen the system against possible pollution or cooperated quality throughout disasters. Maintenance food quality diminishes health risks related with insecure or cheap food, encouraging better community health results. Additionally, a sustainable and strong food segment often nurtures local manufacture and supply networks. Localization fortifies resident economies and pays to public health through the security of access to

new, nearby obtained food. Besides, it produces financial stability within those societies, providing for continuous living and establishment community flexibility. The union of sustainability and flexibility motivates environmental agreement and recovering groups. Sustainability practices facilitate environmental deprivation and reduce negative health impacts connected with contaminants or unmaintainable agricultural systems. When combined, flexibility policies confirm that these environmental benefits persevere even during stimulating times, after all contribute to enhanced community well-being results and overall public comfort (Sutar et al., 2025).

Nanotechnology provides an advanced path to enhance sustainability and flexibility within the food industry, thereby contribute meaningfully to the search for food safety. Its demand suggests numerous benefits, primarily enhancing food protection, safety, and source consumption. Nanomaterials, such as nano enzymes and advanced packaging, enhance food organizations' flexibility against numerous tasks. The main advantage lies in their ability to extend the shelf life of easily spoiled foods. Nano based packaging ingredients create barriers that reduce oxygen exposure, humidity, and bacterial growth, thereby preserving food freshness for longer periods. This extended shelf life reduces food wastage and ensures a stronger food supply chain, lowering losses during transportation and storage. Furthermore, nanotechnology aids in stimulating food safety measures. Nano sized elements have antimicrobial properties, which enable them to combat pathogens and reduce pollution dangers. By integrating these elements into wrapper ingredients or diet exteriors, nanotechnology forcefully guards against spoilage and foodborne diseases, enhancing overall food safety and flexibility against possible health risks (Seyam et al., 2024)

Moreover, nanotechnology encourages supply productivity in food manufacture. Nano based transport organizations for nutrients, insecticides, or enrichers permit accurate and embattled claim, dropping source depletion and ecological effect. This skill donates to sustainable cultivated practices by enhancing source consumption, safeguarding an extra strong and globally conscious food manufacture system. Moreover, nanotechnology proposals fresh methods for detection impurities or contaminants in food, attractive traceability and value controller. These progressive discovery instruments donate to improved slide and belief in the food source chain, expanding flexibility in contradiction of fake performs and encouraging total food safety. Iqbal et al. (2025) illustrated consideration to matters such as deprived produce traceability, interrupted produce flow, food fabricating before adulteration, and contrary community well-being things. They highlighted the requirement for more investigate to increase a profounder kind of these worries and develop applied results. Herein situation, blockchain skill develops as a tough maintainable method, if societal, financial, and ecological and therefore stimulating Food supply chain against disturbances. Its requests extent from farm to fork, safeguarding the genuineness and validity of foodstuffs and supporting flexibility by restriction cybercrime and copying. Blockchain technology useful in food traceability is a game-changer in progressing sustainability and flexibility for confirming food safety. This execution transforms supply chain transparency by creating a fixed record, permitting food traceability from farm to fork. This slide reduces hazards like scam or adulteration, safeguarding genuineness and responsibility through the supply chain. By quickly recognizing and speaking matters, blockchain improves flexibility in contradiction of disturbances such as infections or supply chain matters, safeguarding food security. Moreover, this slide permits customers to favor moral and maintainable foodstuffs, inspiring answerable selections. Participating blockchain with Internet of things and Frid technologies more supports traceability, enhancing transparency, modifying hazards, and encouraging sustainability. This inclusive method is critical in healthy food organizations, sustainability, flexibility, and total safety, meaningfully affecting worldwide food safety enterprises. Biotechnology, for example, enables the growth of inherently improved yields extra resilient to pests, illnesses, and severe climatical conditions, safeguarding improved produces and food obtainability. Precision agriculture, additional technological progress, enhances resource utilization by utilizing gadgets, drones, and data analytics to deliver water, nutrients, and pesticides with precision, reducing waste and environmental impact while enhancing productivity. Additionally, food processing technologies help preserve food, reduce spoilage, and extend the shelf life of perishables, thereby reducing food losses and contributing to food security. All these technological interventions enhance sustainability by reducing supply chain and environmental impact and enhance resilience by creating healthier and more resilient food systems capable of withstanding multiple shocks, thereby ultimately contributing to global food security. This technology promotes sustainable sustainability and resiliency by fostering economic opportunity and fostering investor collaboration. (Haji et al., 2024) have identified the role of food science and technology in charitable replies and emphasized consumers, preferential for local food systems. By deploying these technologies, we can enhance food safety, stimulate service, and revitalize local economies, thus contributing to robust and sustainable food entities.

Other maintainable policy for stimulating food organizations includes life cycle assessment, which is critical in reinforcing sustainability and flexibility and eventually attaining food safety. This policy entails approving short- and long-term sustainable policies, counting safeguarding work drive, appraising strategies related to flexibility, and emphasizing survivability in the list organization, industrial, and transport.

Organized sustenance of humanoid possessions, transport logistics and provincial strategies theatres an essential part in overwhelming deficiencies and attractive flexibility. Life cycle assessment judges the ecological effects of nutrition manufacture schemes through their whole life cycle-from removal of raw materials to processing, supply, eating, and leftover discarding. This valuation permits the sponsors to recognize and lessen ecological flashpoints, improve source consumption, and lessen leftover group on separately step of nutrition manufacture. Through measuring the ecological mark of food manufacture, Life cycle assessment supports making informed outcomes to enhance sustainability, such by way of selecting extra eco-friendly manufacture systems, dropping greenhouse gas productions, and diminishing marine procedure. Besides, by recognizing exposures in the food supply chain, life cycle assessment donates to enhancing flexibility against disturbances by allowing the progress of policies to lessen hazards and build extra healthy and flexible food systems. This inclusive investigation nurtures extra maintainable and strong nutrition construction land, which is critical for reaching long-term food safety goals. This framework aids as a controlling scope in showing the role and impression of maintainable policies on healthy nutrition organizations that eventually protect the safety of the food and improve health (Haji et al., 2024).

***Future Prospects*:** Adoption of new technologies will be rapid and well- founded that will determine the future of the food supply chain of Pakistan. These tools as artificial intelligence (AI), the Internet of Things (IoT), blockchain, robotics, and big-data analytics might assist in bridging most of the existing gaps that exist in the domain, whether it is inefficient logistics or significant after-harvest losses (Ghaffar et al., 2025). Combing in conjunction with climate-resilient agriculture practices, automated distribution and renewable energy solutions, such technologies can contribute to food security on a long-term basis. The increasing heat, the decreasing natural resources, and the increasing global demands of the world are exerting unprecedented pressure on the food systems. Artificial intelligence and similar solutions, including machine learning algorithms, automated control solutions and massive data analytics offer effective strategies for mitigating this pressure. An example is predictive models alerting of probable shortages in yields that occur in practice, and an intelligent routing system that can minimize transportation inefficiencies; both of these can reduce waste and greenhouse gas emissions. AI-based precision farming may also assist farmers to boost production, reducing the number of fertilizers and pesticides (Anwar et al., 2023).

There are other examples where blockchain has been used to enhance, improve supply chain traceability and operational efficiency across agriculture value chains and, in some cases, increase the income of smallholder agricultural participants. Nonetheless, African and Indian studies further prove that technology is not a panacea: the policy should support its adoption, and appropriate training and adjustments to the local market frameworks are required. The body of empirical evidence pertaining to Pakistan is yet to be fully developed, particularly in other provinces like Punjab and targeted field studies are required to comprehend how blockchain would work in the area (Ghaffar et al., 2025). The uniform increase in global population underscores the requirement for safe and diverse food production and distribution of nutritious foods-which are not always efficient with the help of old-fashioned methods of processing. Robotics and automation may also fill in the latter: the latter increase consistency and accelerate repetitive processes, reduce the chances of contamination by minimizing the effect of manual work. In reality, companies are already deploying robotic systems in meat, dairy and seafood processing and packaging conveyor belts; the robots lower the degree of labour utilization and enhance throughput and homogeneity of the product (Sib-e-Abbas et al., 2023).

Pakistan must unite innovativeness with coordination to change the technology hope into reality. By collaborating with the government and institutions and firms of higher learning, the necessary regulatory, training, and financial framework ought to be established to boost investment and uptake. Improving the rural ICT infrastructure, making farmers digitally literate, and integrating blockchain-enabled traceability where appropriate, and renewable-energy-based cold storage are a possible solution that will enable reducing losses and improving transparency (Dong et al., 2023). Such measures would enable Pakistan to move to a more resilient and technology-enabled food system in accordance with the national food policy and the international sustainability objectives. Some of the issues that are impeding the food supply chain in Pakistan include climate change, bottlenecks in infrastructure, post-harvest, and lack of effective coordination among the stakeholders. However, it has been announced that the new technologies, such as the artificial intelligence (AI), the Internet of Things (IoT), blockchain, robotics, and data analytics, provide the opportunity to revolutionize this system. Such inventions can help enhance traceability, reduce inefficiency and establish transparency in the production storage, distribution and retail processes. Improving supply chain predictability and efficiency via real-time monitoring, which will occur thanks to digitalization, will create fewer losses and food security.

***Conclusion*:** Food supply chain in Pakistan is experiencing severe problems such as climate change, infrastructural disparities, post harvests losses and lack of coordination among stakeholders. Nonetheless, the adoption of new technologies, including artificial intelligence (AI), the Internet of Things (IoT), blockchain, robotics and data analytics is an opportunity to transform this system. The innovations can be used to improve traceability, minimize inefficiencies, and can provide transparency throughout the production, storage, distribution and retail phases. The

digitalization also allows making predictions and optimizing logistics and real-time control of all of them contribute to decreasing losses and food security. Despite these advantages, deficiencies in the right institutional structures and favorable policies such as inadequate infrastructure, low digital literacy, and expensive implementation are some of the barriers that have to be waded to cover. The government, the academic and the private sector need to collaborate in the search of solutions that are sustainable and technology-based. Some of the initiatives that can be made towards achieving resilience and inclusivity in the food system are blockchain-owned traceability systems, cold storage powered by renewable energy, and the digital literacy of farmers.

The final product is that the manner in which Pakistan can succeed in attaining effective food supply chain is by taking into consideration the fusion of technology application with capacity creation, availability of funds and policy making supported by facts. In this manner, the nation will be capable of minimizing food waste and environmental expenditures, in addition to, creating a model of novelty and sustainability within the area. Such digital and smart systems will transform the agricultural landscape in Pakistan into a productive, fair, and sustainable landscape that can absorb the economic and climate issues that are going to happen in the future when the efforts are well put.

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***Policy Referred*:** National Food Security Policy (2018); National Climate Change Policy (Updated 2021); Pakistan Vision 2025; Digital Pakistan Policy.

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